

# **Tale of Two Fusion Approaches: Tokamaks and RMF-FRCs**

**Presented by Steve Tobin**

**Research Performed in Collaboration with UM, SNL, DRFC, ORNL,  
LANL & RPPL(UW)**

This talk is to be given at the Office of Fusion Energy Science (Germantown, Maryland) at which I am applying for the position of Assistant Director to the Alternative Concepts Program. It is an overview of my experiences in fusion energy science research. As such it is divided into two parts, the work performed as a graduate student and that which was done as a postdoctoral researcher. The graduate work was performed in collaboration with The University of Michigan, Sandia National Laboratory, the French Fusion Research Division (DRFC) and Oak Ridge National Laboratory. This research (slides 4 to 13) addresses impurity production and its diagnosis on the Tore Supra Tokamak. The remainder of the presentation (slide 14 to the end) is an overview of the research performed as a postdoctoral researcher at LANL. My postdoctoral research has been performed at LANL and at the University of Washington. At LANL we built the electronics which powers a rotating magnetic field (RMF) current drive system. The University of Washington's Redmond Plasma Physics Laboratory is the site of the Translation Confinement and Sustainment Experiment (TCS). The LANL built RMF system is used to generate field-reversed configuration (FRC) plasma at TCS. The focus of my research has been to determine the power balance in the RMF generated FRC.



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# Overview

- 1) Tore Supra [UM, SNL, DRFC and ORNL]
  - a) Role of Impurities: *Cool Plasma & Destruction*
  - b) Sputtering Mechanisms: *Physical, Chemical and Radiation Enhanced Sublimation (RES)*
  - c) Experimental Approach: *Visible Endoscope*
  - d) Conclusions

# Overview (Cont.)

- 2) Translation, Confinement and Sustainment Exp.  
[RPPL(UW) & LANL].
  - a) Description of Experiment.
  - b) Construction of Amplifier System.
  - c) Power Measurements.

# Wall Materials (Impurities) Removed by Non-confined Particles

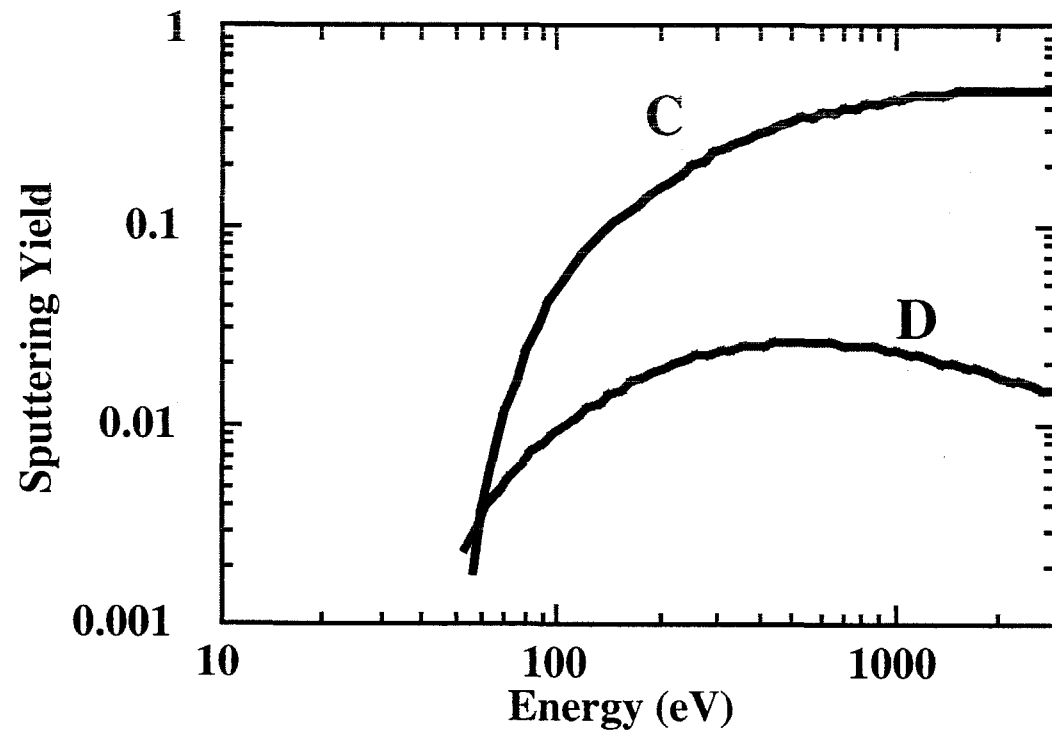
## Results:

- 1) Cool Plasma (radiation  $\Rightarrow z^2$ )
- 2) Damage Walls (melt, erode)

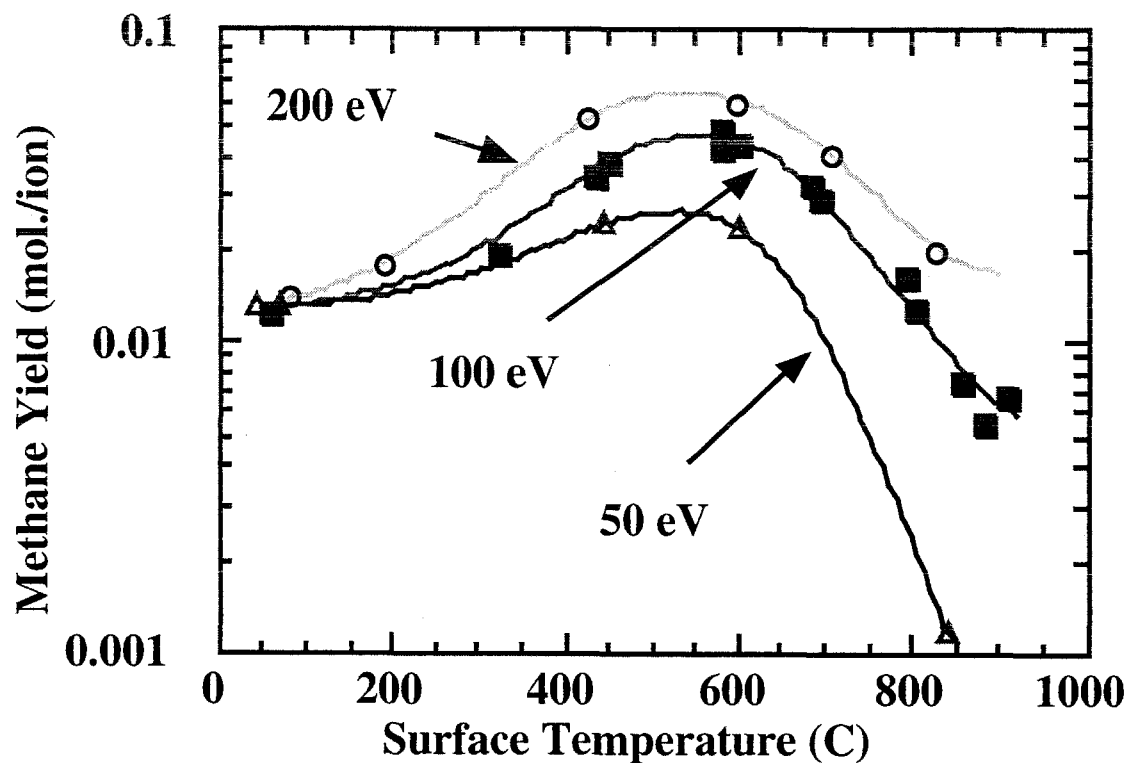
# **Research Focus:**

- 1. Determine Mechanisms for Impurity Production**
  - a) Physical Sputtering**
  - b) Chemical Sputtering**
  - c) Radiation Enhance Sublimation (RES)**
- 2. Global Impurity Balance**
  - a) Source Term**
  - b) 3D Edge Impurity Code**
  - c) 1D Core Code**

# Physical Sputtering Depends on Impact Energy



# Chemical Sputtering Depends on Surface Temperature





# **Radiation Enhanced Sublimation Depends on Surface Temperature**

- **Exponential Increase  $\Rightarrow \exp(-E_{\text{res}}/kT)$**
- **$E_{\text{res}} = 0.78 \text{ eV}$**
- **Initiated at  $\sim 1000^\circ\text{C}$**

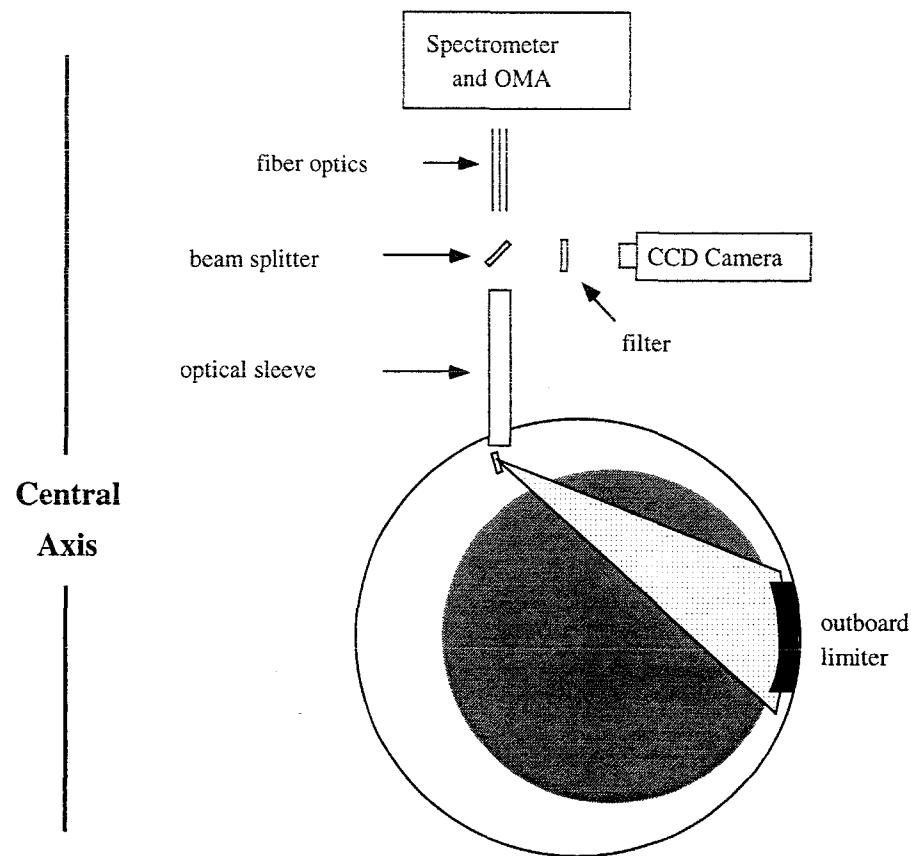
# Global Impurity Balance

- 1) Carbon brightness (photon/s/cm<sup>2</sup>/sr) determined experimentally with visible spectroscopy (spatial distribution).
- 2) 1D core code utilizes core diagnostics to determines quantity of carbon and ionization state at 2 cm from limiter.
- 3) 3D edge Monte Carlo impurity code interface between carbon at 2 cm and carbon brightness. Edge transport varied to see if agreement could be made at 2 cm surface.

# Experimental Plan

1. Isolate plasma against one limiter.
  - Vary particle energy
  - Vary surface temperature
2. Observe limiter with 2D visible and infrared diagnostics.
  - Record CII, CIII and  $D_\alpha$  images
  - Record infrared images

# Visible and IR Endoscope



# **Tore Supra Research Conclusions**

## **1) Impurity Production Results:**

**a) RES observed as in ion beam exp.**

- initiated at  $\sim 1150^{\circ}\text{C}$ ,
- no visible impact on core carbon

**b) Chemical sputtering present**

- slight increase in particles emitting CII
- re-deposited during breakup chain

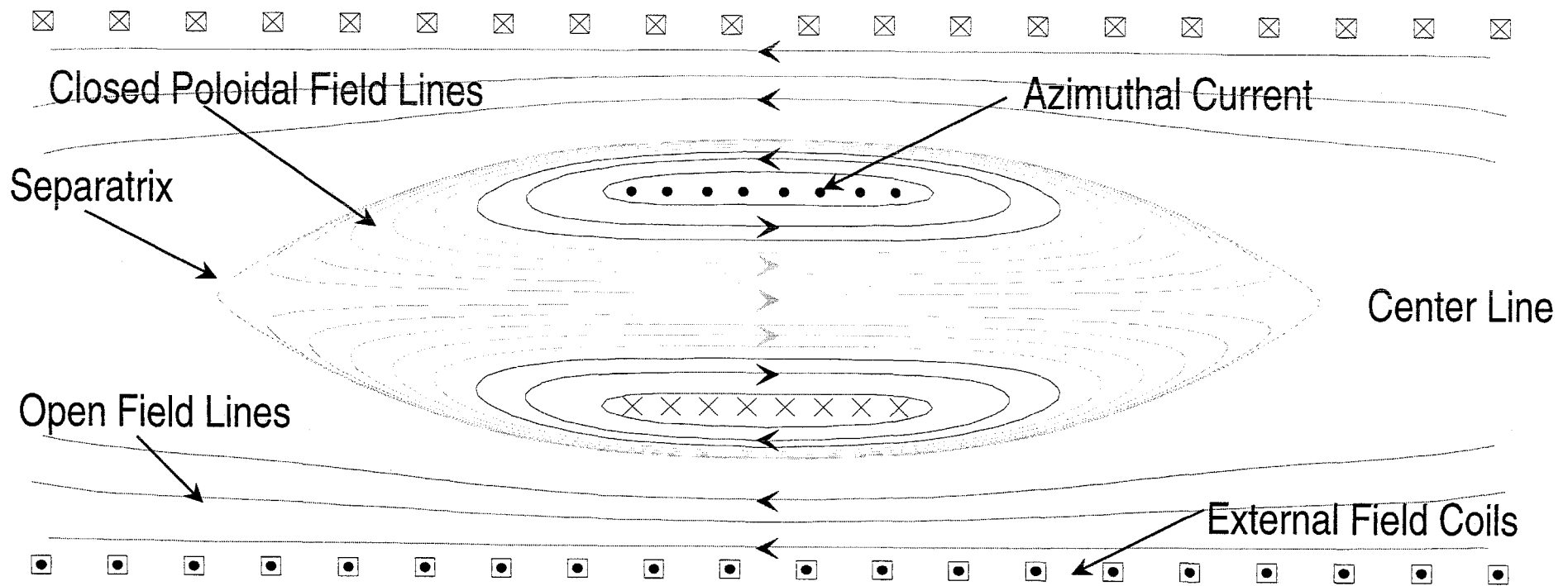
**c) Physical sputtering dominant in core and edge**

- constant CII & CIII for  $T_{\text{sur}} < 1150^{\circ}\text{C}$

## **2) Reasonable agreement between 1D core and 3D edge codes**

# The Field Reversed Configuration (FRC)

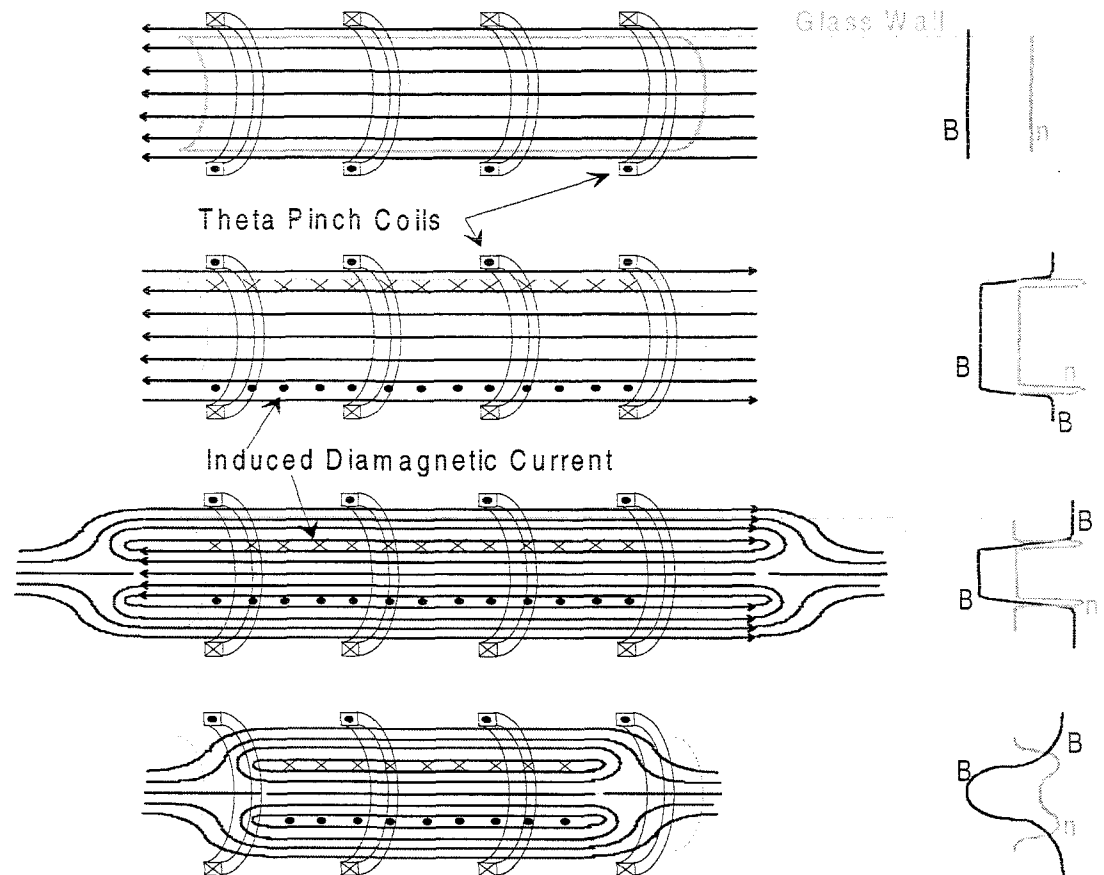
A self confined current ring, held in an external axial magnetic field



$$B_{\phi} = 0, \quad \beta \sim 1$$

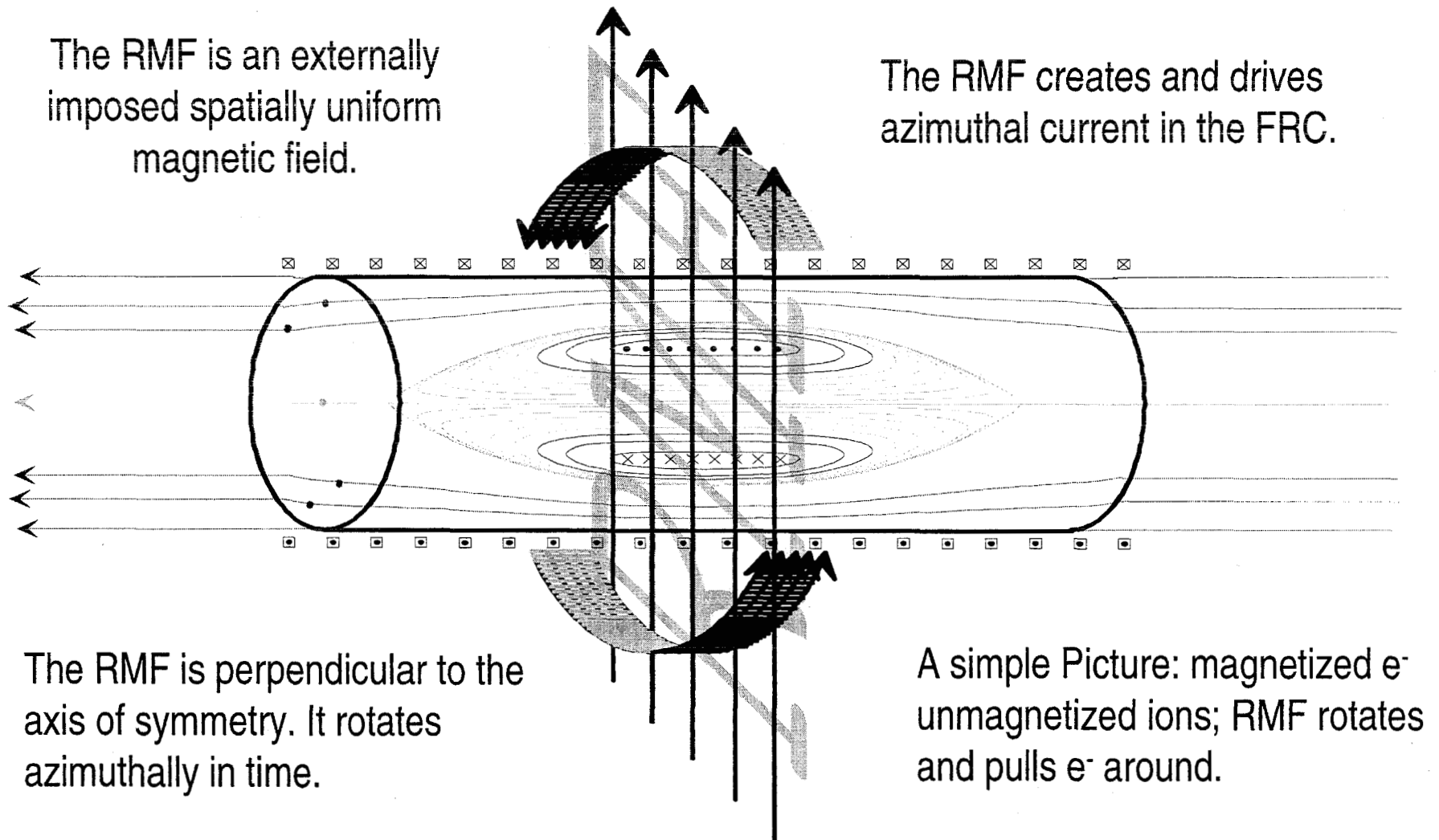
# Conventional FRC Formation (FRTP)

- 1) Start with uniform B in magnetized plasma.
- 2) Reverse B. Plasma forced into the wall. Induced azimuthal current flows due to  $\int \mathbf{E} \cdot d\mathbf{l} = d\Phi/dt$ .
- 3) Radial compression from  $\mathbf{j} \times \mathbf{B}$ . Plasma pushed off wall.
- 4) Field lines reconnect, axial Implosion. Equilibrium.



- From the changing magnetic field, a diamagnetic current ( $I_\theta$ ) is produced.
- No sustainment,  $I_\theta$  decays resistively, life determined by trapped flux.

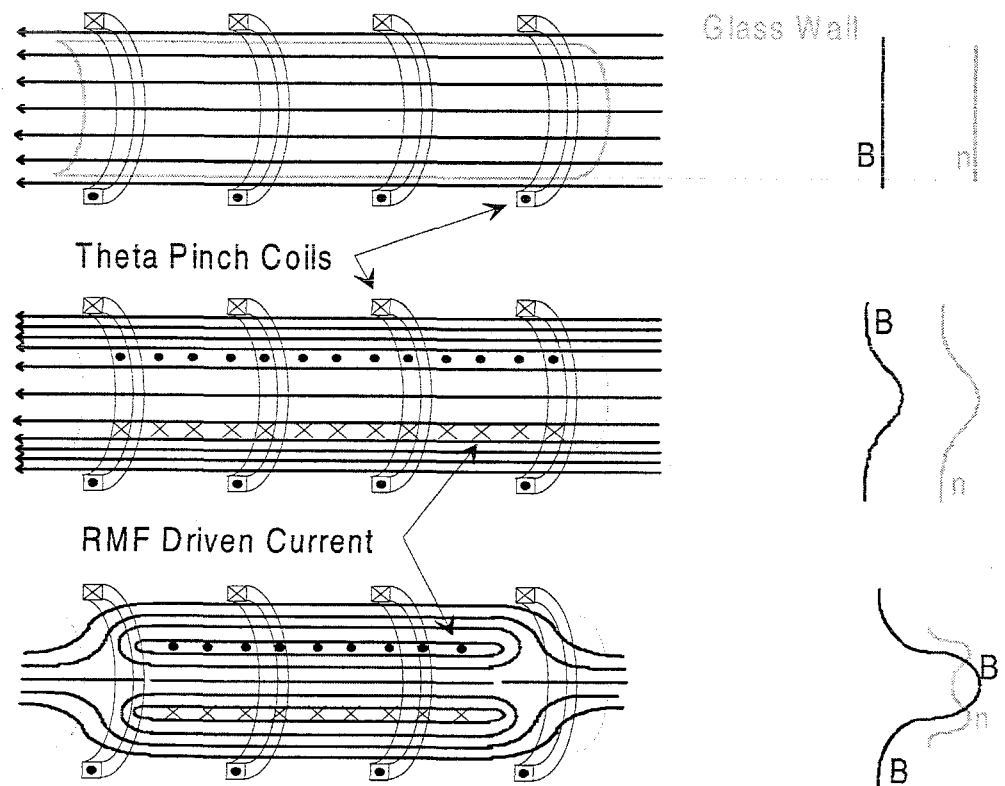
# The Rotating Magnetic Field (RMF)





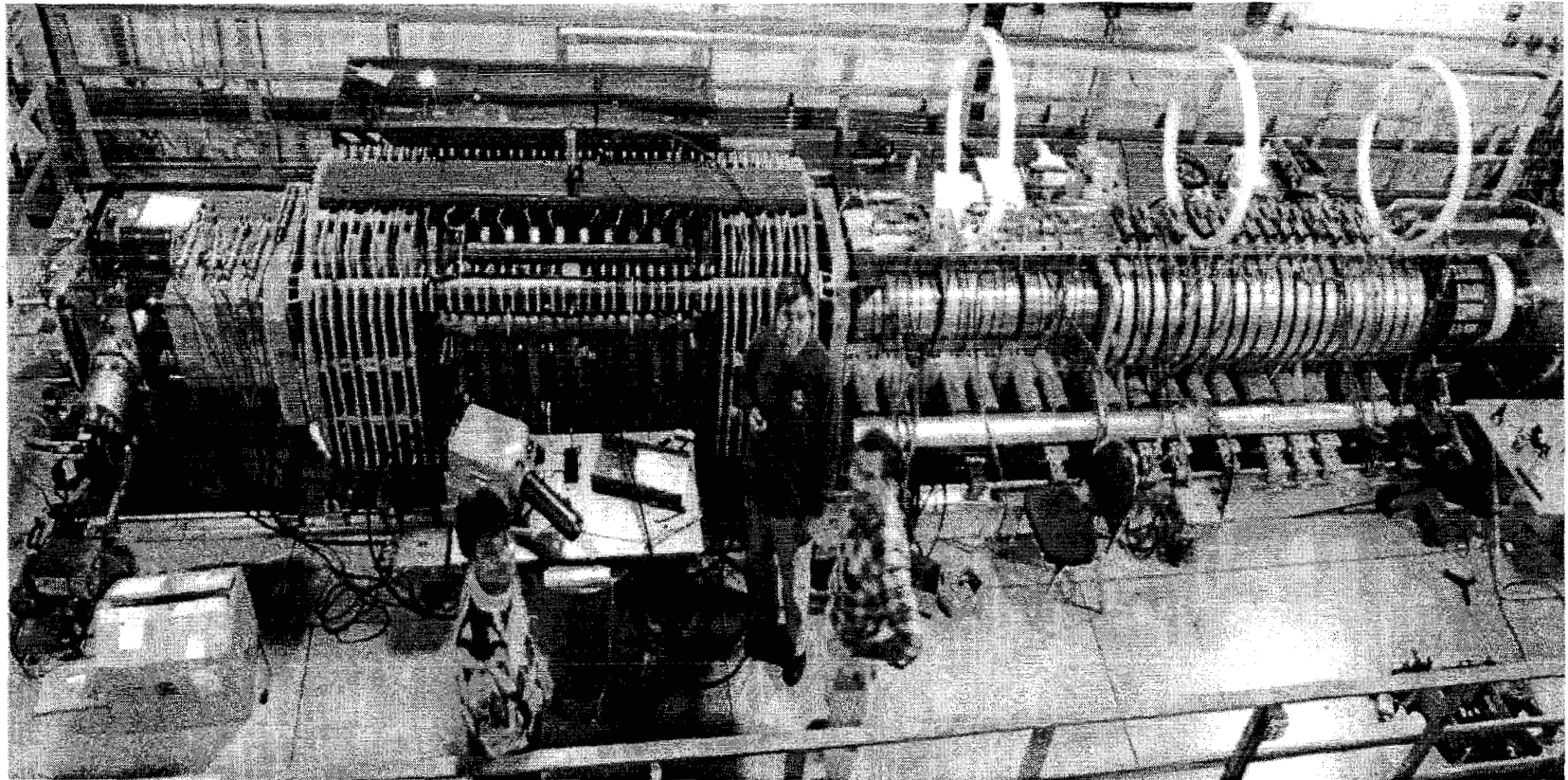
# Rotating Magnetic Field FRC Formation and Sustainment

- 1) Start with Uniform  $B$  in partially magnetized plasma.
- 2) Turn the RMF on. It drives  $I_\theta$ . The magnetic field associated with  $I_\theta$  alters the axial magnetic field.
- 3)  $I_\theta$  reverses the axial magnetic field. An FRC is formed.



- Driven  $I_\theta$  sustains the FRC indefinitely. Plasma stays off wall.

# TCS Experiment



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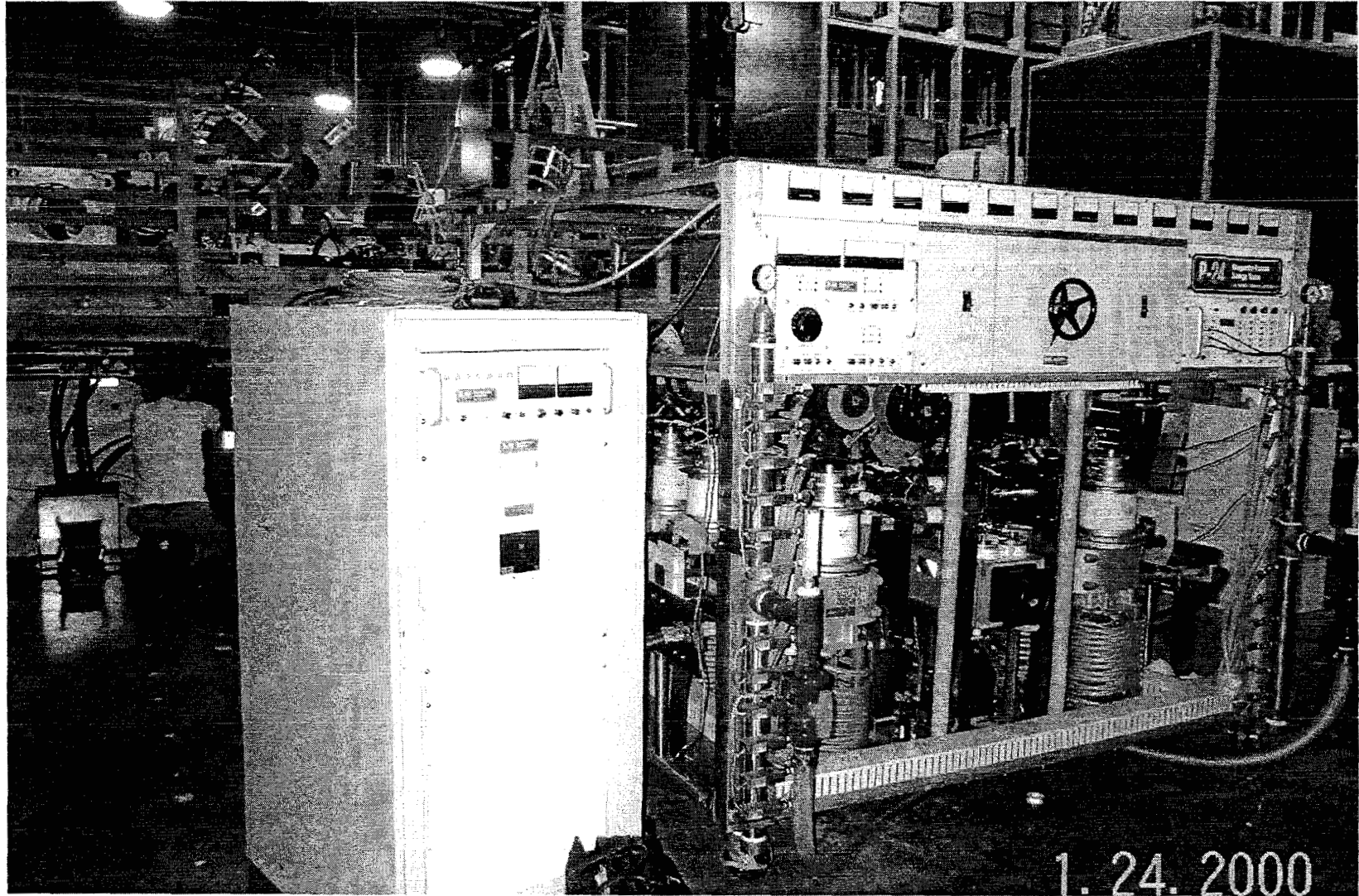
# Time Line of TCS

- 1) 1<sup>st</sup> steady state FRC formed in May 2000.
- 2) RMF formed FRC subject of first year of operation (2 frequency regimes).
- 3) Translated FRTP formed FRCs to start this month.

# Focus of my postdoctoral Research

- 1) **Fabrication and Testing of system which powers the RMF**
- 2) **Power Balance**
  - **measured total power delivered to plasma**
  - **investigated where it went**

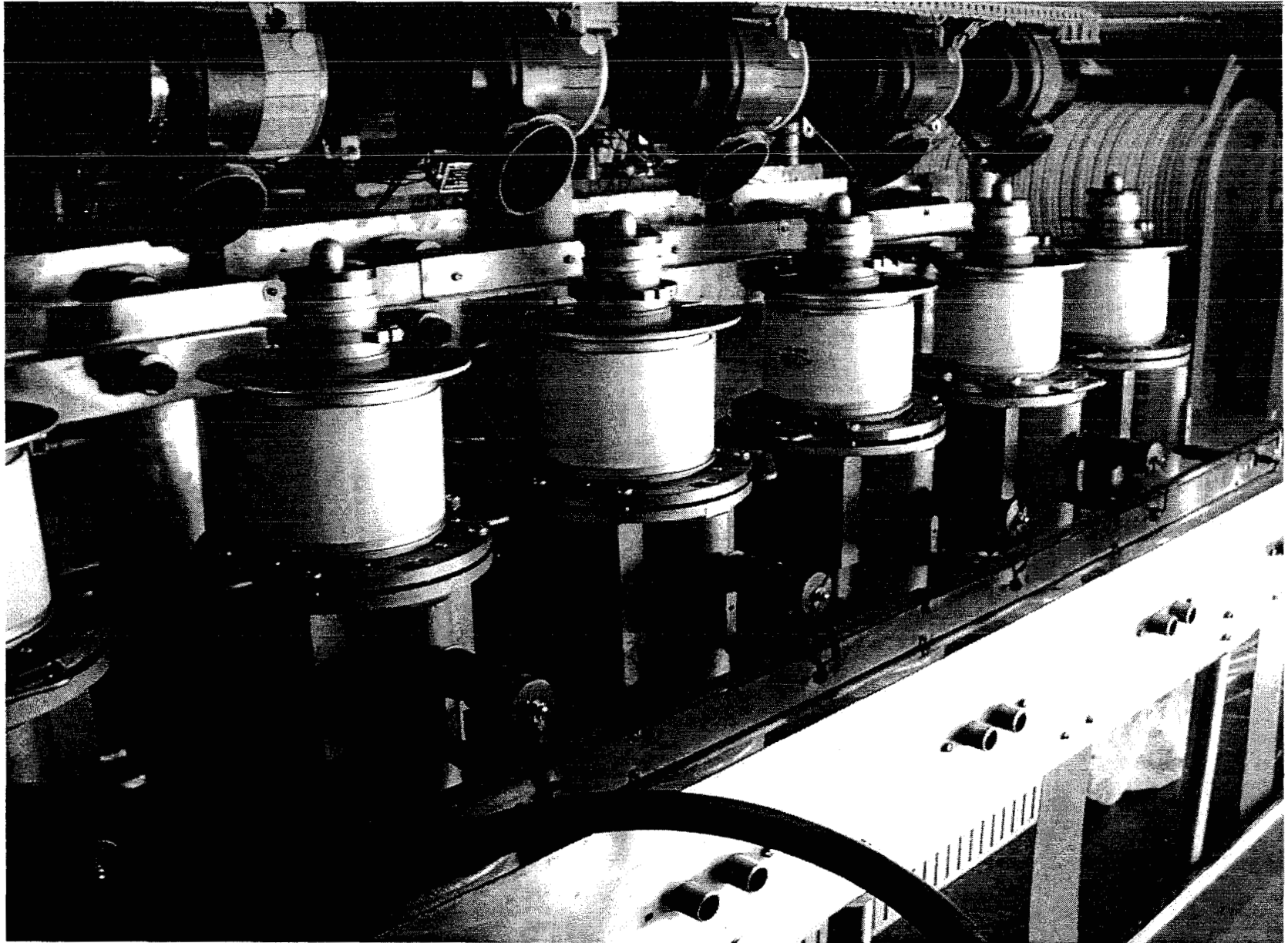
# LANL's Amplifier Unit with TCS



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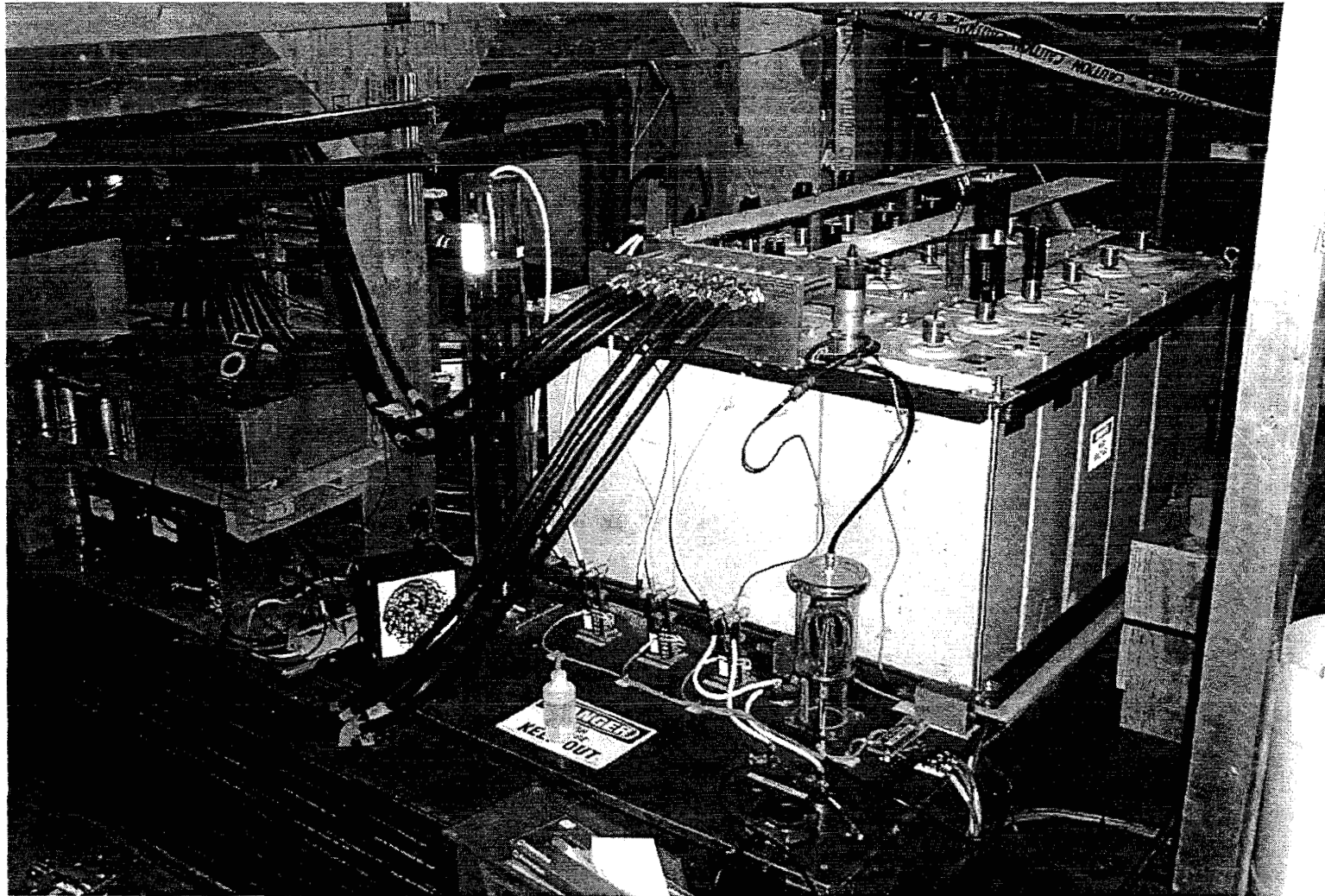


# Machlett tubes





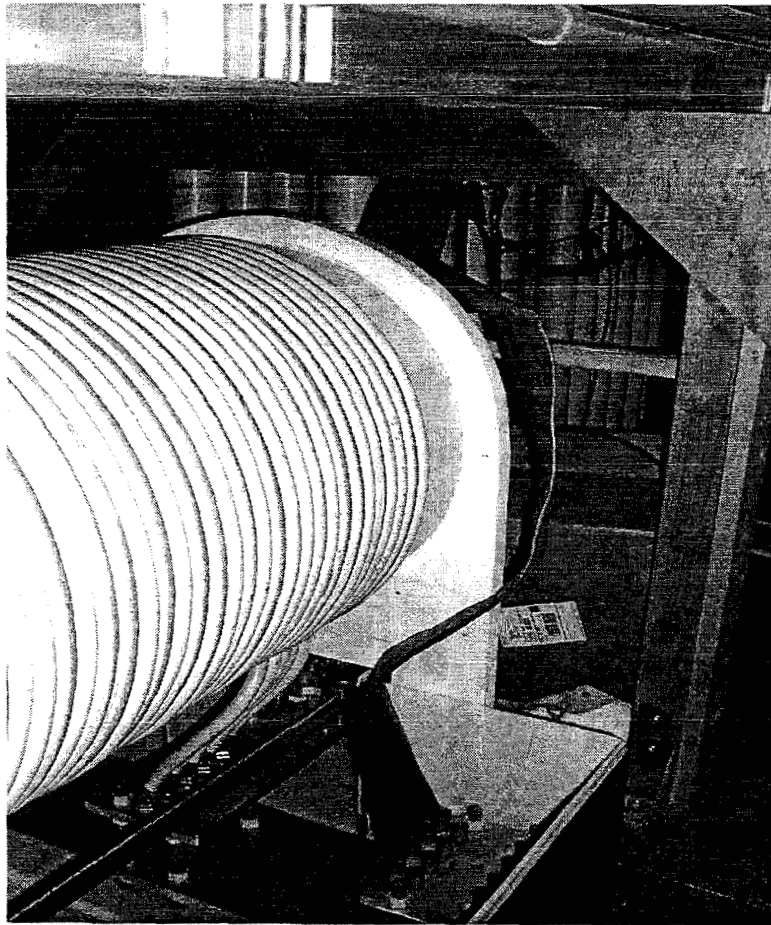
# 1 mF Main Capacitor Bank



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# 1 : 1 Transformer & RF Capacitors



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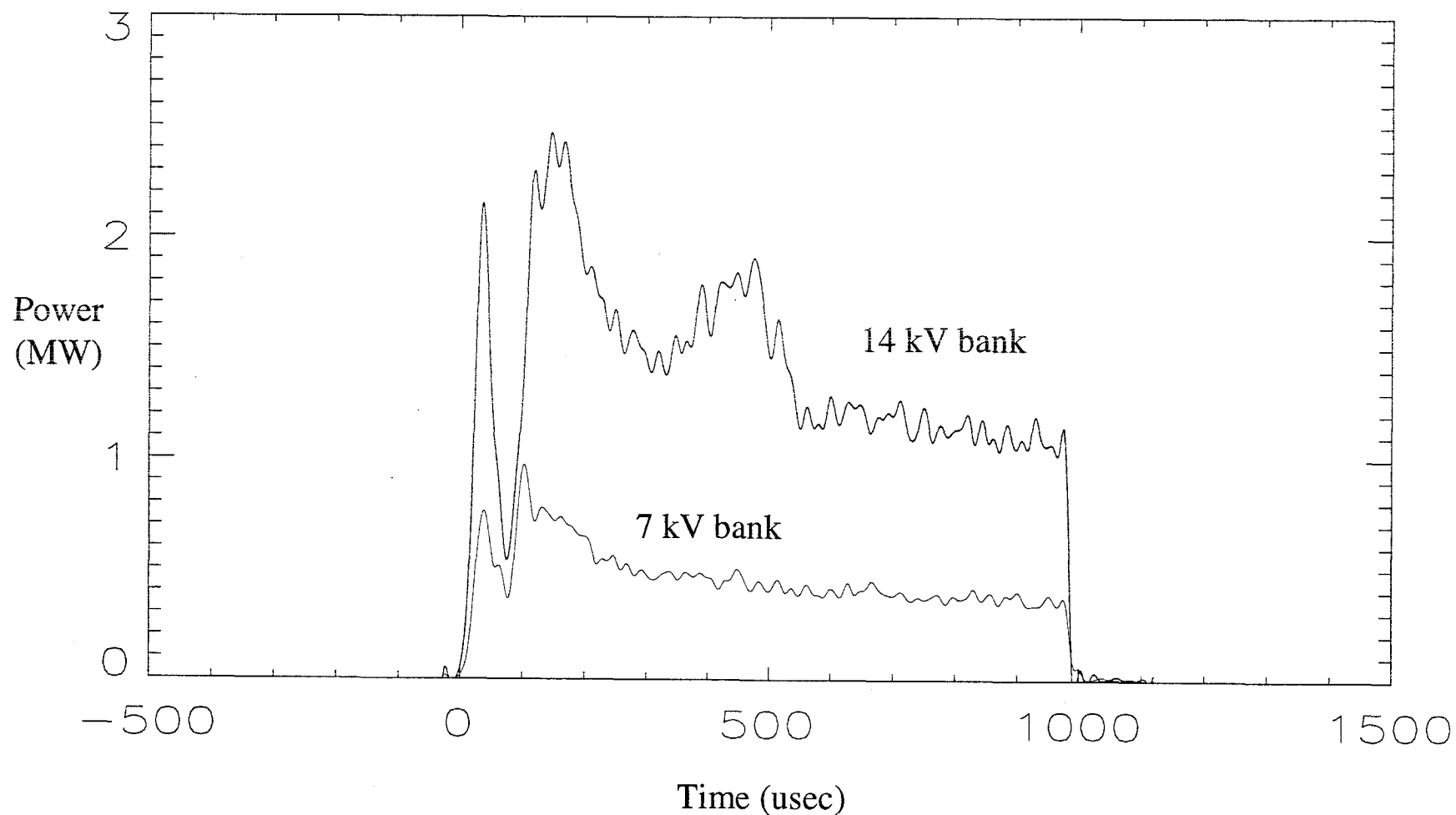




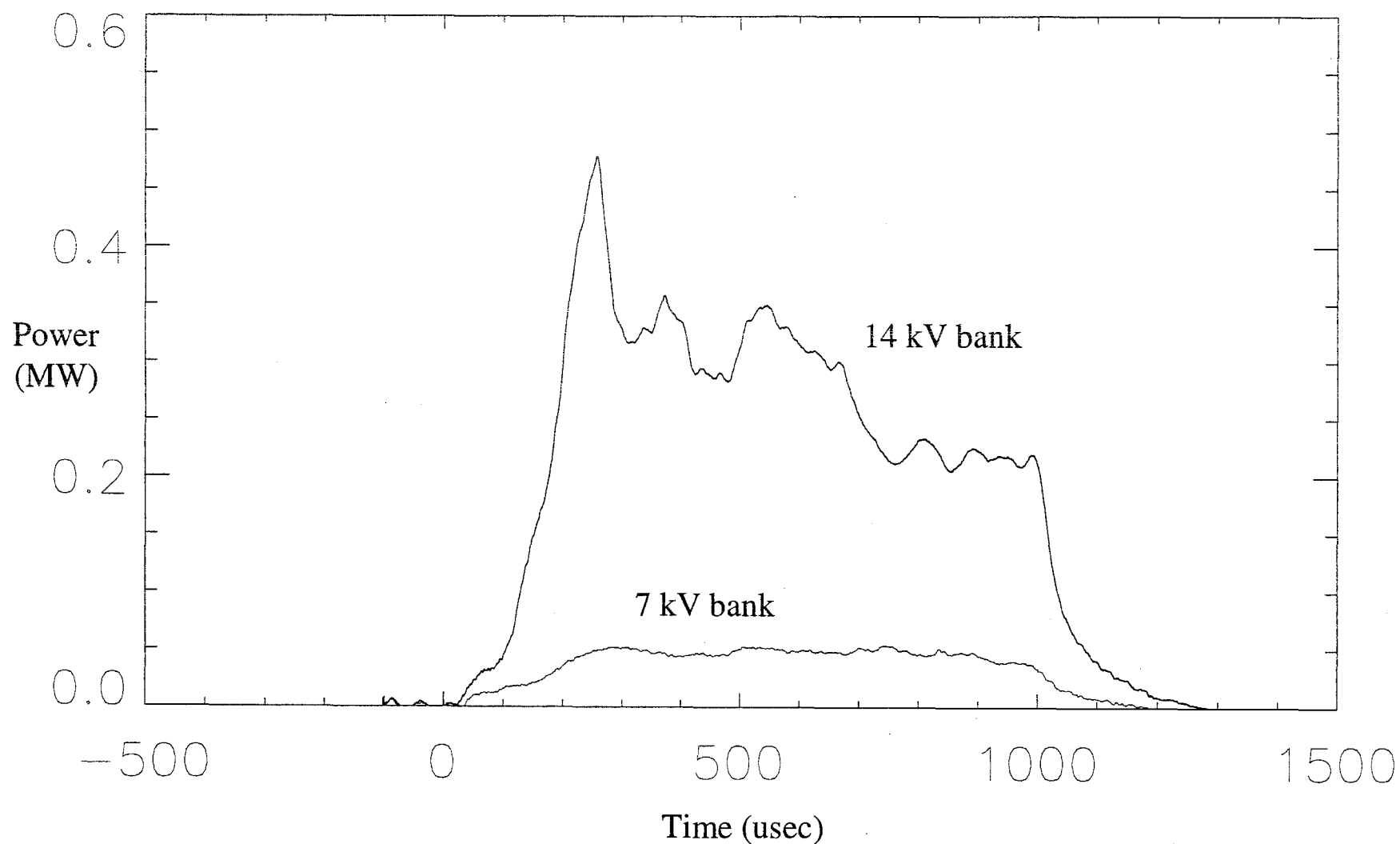
# Power Balance

1. Total energy in plasma =  $\int V * I \, dt - \int I^2 * r_{\text{circuit}} \, dt$
2. Radiated power measured with bolometer
3. Ionization, charge exchange and convection determined from plasma conditions.

# Power Dissipated into the plasma



# Power Radiated from the plasma measured with Bolometer



# **TCS Conclusions**

- 1. Successfully constructed and installed amplifier system to power RMF.**
- 2. Power Balance**
  - Measured Total Power into the plasma**
  - In process of examining where power goes.**
- 3. RMF formed FRC campaign completed.**
  - Steady state operation**
- 4. Starting translated FRCs this month.**